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ORIGINAL PAPER

Application of the TOA-MD model to assess adoption potential of improved sweet potato technologies by rural poor farm households under climate change: the case of Kabale district in Uganda

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Abstract Sweet potato technologies that increase productivity, such as drought resistant varieties and virus free planting material are being promoted in order to reduce the vulnerability of poor farm households to climate change. In this paper, the Trade-off Analysis, Minimum Data Model Approach (TOA-MD) was used to assess the adoption potential of these technologies by resource poor farmers under climate change in Uganda. The model was calibrated and validated using household survey data collected in 2009 from Kabale district. To simulate adoption potential, the base system data was generated from household data and adjusted to reflect impact of climate change on crop yields and prices by 2050. The percentage increase in yields resulting from the use of climate resilient sweet potato technologies were used to estimate yields for alternative systems based on the results from sweet potato trials by the National Agricultural Research Organization (NARO), Uganda. Adoption potential of sweet potato technologies varied across altitudes. Compared with the high and lower altitudes, adoption potential is lowest at moderate altitude despite higher yields and lower costs of production. Paying farmers to adopt new sweet potato technologies is economically rational at the higher and moderate altitudes but not at the lower altitudes. The provision of free planting material (subsidy) for the evaluated technologies resulted in a modest increase of 2 % in adoption potential. Therefore, providing this as a way of increasing adoption of sweet potato technologies to reduce vulnerability of poor farm households to climate change will have a very small impact. Instead, climate change adaptation policy should focus on creating enabling environments for farmers to market their produce so as to raise returns and reduce the opportunity costs of climate change adaptation strategies.

Keywords Drought resistant varieties and Virus free planting material · TOA-MD

Introduction

Climate change threatens to intensify development challenges already confronting the African continent, including food and water insecurity, widening and deepening poverty, HIV/AIDS, and ineffective governance (Intergovernmental Panel on Climate Change (IPCC) 2001, 2007). Uganda's agricultural sector, which contributes 42 % of the GDP, over 90 % of export earnings and employs 80 % of the population, is highly vulnerable to variation in climate (Orindi and Eriksen 2005; Oxfam 2008). Uganda's vulnerability can be clearly seen, based on macro level indicators such as heavy dependence on rain-fed agriculture, weak institutional capacity, limited skills and equipment for disaster management, limited financial resources and increasing population (Orindi and Eriksen 2005).

Stäubli et al. (2008) argue that the main problems affecting potatoes and sweet potatoes such as disease and pest pressure are mainly a result of change in climate. The increase in incidence of infection of sweet potato virus diseases in south western Uganda (Kabale) could be a result of the rise in temperatures as the three common viruses known as sweet potato chlorotic stunt virus (SPCSV), sweet potato feathery mottle virus (SPFMV) and sweet potato mild

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speckling virus (SPMSV) tend to survive at 26–28 °C (Nome et al. 2007). Sweet potato virus diseases can cause 65 to 72 % reduction in yields from different cultivars according to Gutierrez et al. (2003) but experimental results from the collaborative sweet potato project between the National Agricultural Research Organization (NARO) and International Potato Centre (CIP) gave losses ranging from 56 to 100 % (Gasura et al. 2008). Fortunately, there are new innovations in sweet potato production that are thought to increase resilience of agricultural systems and reduce vulnerability of poor farm households to climate change. These innovations include eliminating sweet potato vines of viruses by thermotherapy in tissue culture, testing for any residual virus by virus indexing and the use of pest and disease resistant varieties. These resistant varieties include NASPOT 1 (Gibson 2005), Munyera, New Kawongo and Polyster (Gasura et al. 2008; Mwanga and Odongo 2009). Removing viruses from planting material was found to increase yields by over 56 % (Mukasa et al. 2006). Virus resistant varieties and virus free planting material are being developed and promoted to increase resilience of the agricultural system to climate change. Nonetheless, adoption of these technologies remains low at about 20 % (Yaggen and Nagujja 2005; Bashaasha 2009) and this is mainly attributed to limited household capital and access to rural services (Nkonya et al. 2012). Moreover, there are no studies in Uganda that have examined the benefits, costs, and adoption of technologies considered to enhance resilience to climate change. These are the subjects of this paper. The rest of the paper is organized as follows: section two describes the study materials and methods; section three presents and discusses the results and section four discusses the policy implications of the study.

Materials and methods

Study area

The study was implemented in Kabale District, which lies in the south-western corner of Uganda between latitudes 1°S and 1° 30 S and longitude 29° 18 E and 30° 9E. It is characterized by hilly, mountainous terrain and a relatively high altitude of 1,500–3,000 m above sea level. It has a temperate climate, with a mean annual rainfall of 1,000–1,500 mm and temperatures ranging from 10 to 23 °C. The district has the highest population density in rural Uganda, and pressure on land resources has been a problem since the 1940s. High population density combined with the traditional system of land inheritance have resulted in extreme land fragmentation as family plots have been continuously sub-divided with each generation (Lindblade et al. 2000).

Model description

The Tradeoff Analysis, Minimum Data Model (TOA-MD) developed by Antle and Valdivia (2006) for an ex-ante assessment of the adoption of practices was used to estimate the rate of adoption of alternative practices based on economic feasibility. Application of the model was in two phases: phase one involved stakeholders' workshops at the study site in order to develop hypotheses about potential tradeoffs; the second phase involved identification of data needs, collection of data, running the model and construction of trade-off curves for policy analysis. The constructed trade-off curves provided an estimate of the rate of adoption of alternative practices based on their economic feasibility, i.e. differences in returns between alternative practices. It used farm level and plot level socio-economic and bio-physical data to assess the profitability of substituting one practice or system for another. The analysis considered the following issues; first, the returns from adoption of these technologies varied across farms due to the heterogeneity of soil characteristics existing within the farmers' fields. Second, farmers were uncertain of returns due to uncertainty about output prices. Thus, adoption capabilities and the investment to increase adoption rates of these technologies among farmers varied depending on biophysical and economic factors (Khanna et al. 1999, 2000).

MD model for analysis of adoption potentials for sweet potato technologies

To implement the economic analysis, we used the minimum data (MD) approach for modelling the supply of ecosystem services from agriculture, developed by Antle and Valdivia (2006). Whereas other studies of agriculture—environmental interaction processes and policies have used highly complex data, such as the intensive models of Antle and Diagana (2003), the MD approach exploits the structure of the incentive payment problem to obtain an approximation to the adoption potential of sweet potato varieties, using relatively simple secondary data. The MD model assumes farmers make land use and management decisions that maximize their economic returns (benefits). When farmers are not provided with any incentives there is an initial equilibrium adoption level. This adoption level is driven by the farmers' economic motivation but ignores the impact of climate variability on economic variables e.g. yields and prices. To increase adoption of these technologies above this initial equilibrium, NGOs and governments need to provide incentives (subsidies) to sweet potato farmers. In Uganda, NGOs and governments have been subsidizing farmers by providing free planting material (Tanya 2005; Gibson et al. 2007; NAADS 2008; Hall 2009). The challenge, however, is the uncertainty about the amount of subsidy that is required to attain a given level of adoption in a given location. To analyze the problem, we considered two practices or systems. System 1 represents growing of sweet potato under climate change by 2050 with no adoption and system 2 with adoption.

The expected gain in yields in sweet potatoes amounting to $e(\beta)$ kilograms per hectare of adopting drought resistant and disease free technology under climate change is generated at a location β, where $e(\beta)$ is equal to zero if a farmer does not adopt the new technology under climate change. Consequently, $e(\beta)$ is the difference in sweet potato yields between adopting and not adopting new sweet potato technology under climate change. Assuming π_e as the price per kilogram of sweet potato, then the farmer gains returns amounting to $\pi_e(e(\beta))$ per hectare. Therefore, a farmer will decide to adopt new sweet potato technology if

$$\pi_e e(\beta) > 0 \text{ or if } \Omega(\pi,\beta,2)-[\Omega(\pi,\beta,1)] > 0, \tag{1}$$

where Ω is the net return, π is a vector of input and output prices, β indexes the location or site and 1 and 2 indicate the practice or system at the location. In this study, there are two alternative systems and they include drought resistant variety alone (system 2A), and drought resistant variety plus virus free vines (system 2B) as represented in Table 1. The TOA-MD model was used to simulate the adoption level of alternative technologies by comparing each of these technologies with traditional technology under predicted climate change. As the TOA-MD model compares two systems at a time (Claessens et al. 2012), the index 2 in Eq. 1 represents the alternative system being analyzed while 1 represents the base system. Therefore, if we let $\lambda(\pi,\beta)$ represent the opportunity cost of changing from system 1 to system 2 under climate change, then it follows that a farmer will decide to adopt a new technology if

$$\lambda(\pi,\beta)\le\pi_e e(\beta) \tag{2}$$

Where

$$\lambda(\pi,\beta) = \Omega(\pi,\beta,1)-\Omega(\pi,\beta,2) \tag{3}$$

Suppose government or an NGO offers to provide free planting material for the new technology, this is treated as an incentive payment of say π_s to a farmer and can also be viewed as the cost of adoption. In the study area, it was estimated that four bags of sweet potato vines were enough to plant 1 ha. Thus, the cost of adoption (π_s) was estimated to be 40,000 Uganda shillings (approximately US$20) per hectare including transportation to the farm. Therefore, the farmer's gains from adopting a technology would be the sum of returns from new technology with the subsidy offered $[\pi_e e(\beta)+\pi_s]$. Therefore, a farmer will decide to adopt new sweet potato technology if $\pi_e e(\beta)+\pi_s>0$. In other words a farmer will adopt a new technology if

$$\lambda(\pi,\beta)\le[\pi_e e(\beta) + \pi_s] \tag{4}$$

From Eq. 2, it can be deduced that farmers are willing to adopt a new sweet potato variety or technology if the opportunity cost of adopting new sweet potato technology is less than expected returns ($\lambda(\pi,\beta)\le\pi_e e(\beta)$). More precisely, farmers will adopt a new technology if the opportunity cost of producing one kilogram of sweet potatoes is less than the unit price $\left(\frac{\lambda(\pi,\beta)}{e(\beta)}\le\pi_e\right)$. If we order all the locations β for a given price π within a region or an area in increasing order of $\lambda(\pi,\beta)$, we can define the spatial distribution of opportunity cost per hectare e(β), as $\eta\left(\frac{\lambda}{e}\right)$. The fraction of the total number of farmers who adopt new sweet potato varieties without payment is given by

$$\psi(\pi) = \int_{-\infty}^{o}\eta(\lambda/e)d(\lambda/e) \tag{5}$$

The initial number of hectares under new technologies or varieties before farmers are paid to adopt is given by

$$\theta(\pi) = \psi(\pi).H_e \tag{6}$$

Where, H is the total area under sweet potato. Similarly by integrating $\eta\left(\frac{\lambda}{e}\right)$ between zero and π_e, the fraction of the total number of farmers who adopt new varieties is estimated as $\psi(\pi, \pi_e)$. The total area under a new technology or variety equates to

$$\theta(\pi,\pi_e) = \theta(\pi) + \psi(\pi,\pi_e)He \tag{7}$$

To estimate the spatial distribution of opportunity cost of new technology, the MD model uses "Complete" data to estimate site-specific inherent productivity and simulate site-specific farm decisions to construct spatial distribution of returns. By design, the TOA-MD approach estimates the mean, variance and covariance of net returns distributions using plot level data.

$$\lambda = \pi(Y_1-Y_2)-C_1 + C_2 \tag{8}$$

The MD approach uses available data to estimate mean and variance of λ:

$$\mathrm{E}(\lambda) = \mathrm{E}(\Omega_1)-\mathrm{E}(\Omega_2) \tag{9}$$

Expected returns are estimated by impact of new technology as discussed above and as represented in Table 1 below. Fuglie et al. (1999) found that the cost of production and adoption of virus free sweet potato technology is proportional to yields. Thus, it is reasonable to assume that the cost of

Table 1 Data set for model simulations

Regions	Crop activities	Base system (system 1)									System 2A	System 2B
		Cost/ha (Uganda shillings)	Yields kg/ha	Climate change yield impacts (%)	Price/kg (Uganda shillings)	Climate change price impacts	Area (ha)	SD	CV	Weights	Drought resistant variety (%)	Drought resistant variety + virus free vines (%)
Lower slopes	Beans	289,484	1,414.4	11	725	14	10.9	797.3	56.4	0.4	100	100
	Potatoes	301,340	6,670.8	−1.06	325	26	4.3	4722.8	70.8	0.3	100	100
	Sweet- potatoes	128,440	325	−1.06	123.3	26	3.1	4070.8	56.4	0.2	130	169.2
	Sorghum	109,809.1	2,877.6	1.09	500	4	1.4	2874.9	99.9	0.1	100	100
Middle slopes	Beans	125,278.4	1,708.4	11	725	14	1.4	1440.3	84.3	0.2	100	100
	Potatoes	328,510	7,561.5	−1.06	325	26	2.6	4976.3	65.8	0.3	100	100
	Sweet- potatoes	0	6,290.3	−1.06	123.3	26	2.3	5825.4	92.6	0.3	130	169.2
	Sorghum	114,608	3,527.2	1.09	500	4	2.2	3337.8	94.6	0.3	100	100
Upper slopes	Beans	90,985.8	2,746.6	11	725	14	2.2	2877.5	105	0.2	100	100
	Potatoes	62,0175.8	7,096.3	−1.06	325	26	3	4712.4	66.4	0.3	100	100
	Sweet- potatoes	88,920	5,805.2	−1.06	123.3	26	3.1	3297.7	56.8	0.3	130	169.2
	Sorghum	68,295.5	1,443.8	1.09	500	4	1.7	506.6	35.1	0.2	100	100

Source: Field Survey Data (May 2010): The base is the system production of sweet potatoes under climate change without adoption of new technologies. The costs, yields, and price are means computed from household survey data. The climate change yield and price impact are based on climate change impacts projections from the IFPRI's IMPACT water and food projections model by Ringler et al. (2010). These impacts are used in the model to adjust yield and price to account for climate change impacts. Impacts of climate change on costs per hectare are captured by adoption cost. The area is the total land area allocated to production of a particular crop in a given agro-ecological zone or landscape and is computed from the household survey. The area data is used for computing weights for each crop in each agro-ecological zone. The standard deviation (SD) and coefficients of variation (CV) are computed from yields based on the household survey data. The values under system 2A represent percentage increase in sweet potato yields resulting from use of a drought resistant variety while those under system 2B represents increase in sweet potato yields resulting from use of drought resistant variety and virus free vines (planting material). To capture the impact of adoption of sweet potato technologies, we assume that a farmer is not adopting new technologies for the other crops (beans, potatoes and sorghum) production is proportional to yields ($C \approx \kappa Y$) even under climate change because climate change affects both yields and costs (Nelson et al. 2009) and therefore climate change is a shifting factor. The coefficient of variation (CV) in the net returns across land units in the study area can be estimated using yield spatial coefficient of variation. Previous applications of this model support this assumption (Antle and Capalbo 2001; Immerzeel et al. 2008). Thus the opportunity cost is assumed to follow a normal distribution with the mean as Eq. (8) above and variance as $\sigma_\lambda^2=\sigma_1^2+\sigma_2^2-2\sigma_{12}$, where σ_1^2 and σ_2^2 are the variances in net returns of system 1 (old technology) and 2 (new technology), and σ_{12} is the covariance. In the MD model, we assume that all correlations between activities within system 1 are equal (ρ_1), and make the same assumption for system 2 (ρ_2) since they are not always observed (Immerzeel et al. 2008).

Data collection and analysis

Primary data, both qualitative and quantitative, were collected. Two methods where used, namely focus group discussions (FGD) through stakeholder workshops, and household farm surveys. The target population was rural households that were considered to be most affected by the impacts of climate change and also depend on sweet potatoes as the main staple food crop. The stakeholder workshop was conducted at sub-county head quarters. The main objective of the workshop was to obtain information with respect to farmer's knowledge about the impacts of climate change and adaptation strategies. Also, a number of issues were discussed including sources of livelihood, production and farming systems, problems faced by farmers and their coping mechanisms. The workshop was intended to identify scenarios that were relevant for modeling and analysis of data on climate change adaptation, using innovation in sweet potato technologies. Household level data was collected from 120 households randomly sampled from Ikumbya Sub County in Kabale district. Key variables included prices, inputs and outputs (yield) of crops, and land allocation to different crops. Net returns were computed for different crops and for different field locations based on altitude.

Data on cost of planting material, climate change impacts (Table 1) and resilience of sweet potato variety were collected from scientists at the National Agricultural Research Organization (NARO) and other secondary sources. All the data collected were adjusted to meet TOA-MD excel supported software version as shown in Table 1 above. The cost of production estimates the sum of the cost of hired labor, land rent and other inputs. Household labor was not considered in the production costs because rural household labor is usually not considered in computing net returns and the new technologies do not require more labor. Both the traditional and new technologies have the same requirements except that planting materials for new technologies have to be bought and transported to the farm. The costs of the technology and transportation were captured in the cost of adoption. This explains why the cost of sweet potato production is zero in moderate altitudes. Much of the hired labor in lower and higher altitudes was for land clearing and erosion control, which was not the case at moderate altitudes where there were settlements. Yield data for the previous cropping season was collected through a recall method.

To assess and analyze economic feasibility of the adaptation strategies, data from the household survey were calibrated to meet TOA-MD model requirements (Table 1). The base system was considered as the current production system of using locally available planting material adjusted to climate change impacts by 2050 and the alternative systems were the practices aimed at increasing resilience to climate change i.e. using drought resistant varieties (system 2A) and the use of drought resistant varieties plus virus free sweet potato planting material (system 2B). Projections of climate change impact from IFPRI's IMPACT water and food projection model were used (Ringler et al. 2010). The model considered three impacts: (1) direct effects on rain fed yields through changes in temperature and precipitation; (2) indirect effects on irrigated yields from changes in temperature and in water available for irrigation (including precipitation); and (3) autonomous adjustments to area and yield due to price effects and changes in trade flows in the economic model (Nelson et al. 2009; Ringler et al. 2010). Results from this model predicted that climate change would reduce sweet potato yields by 1.06 %, cassava by 0.42 % and maize by 1.92 % by the year 2050 in East Africa. Also, the impacts of climate change on sweet potato and cassava prices were predicted to increase by 26 and 20 %, respectively, and on millet prices by between 4 and 5 % by 2050 (Ringler et al. 2010). To factor in climate change impacts, yields and prices were adjusted by the climate change impacts on these.

To calibrate data for system 2, we used experimental results from the collaborative sweet potato project between the National Agricultural Research Organization (NARO) and International Potato Centre (CIP). Drought resistant varieties, reduced yield losses on average by 30 % (Gasura et al. 2008), while use of virus free planting material reduced yield loss by 56 % on average (Mukasa et al. 2006). We modeled joint use of drought resistant and virus-free planting material against the current practice of using locally available varieties and virus-infected sweet potato vines. As drought resistance is independent of the use of virus-free planting material (Gibson et al 2007), the reduced yield loss resulting from using both drought resistance plus virus free planting material was computed using independent probabilities such that P (AUB) = P (A) + P (B) – P (AnB) = 0.692. P (A) is the probability of reducing yield loss because of using a drought resistant variety (0.30), P (B) is the probability of reducing yield loss because of using virus-free planting material (0.56), P (AnB) is the probability of reducing yield loss that is shared by the two technologies and P (AUB) is the probability of reducing yield loss because of using both drought resistant variety and virus-free planting material. This gives us the reduction in yield loss from using a drought resistant variety, which is virus free.

As indicated above, the costs of crop production in system 1 (C_1) were derived from the household survey. The costs of crop production in systems 2A and 2B (C_{2A} and C_{2A}) were estimated using costs of system 1 and adoption costs. The coefficient of variation of the net returns were assumed to be proportional to the coefficient of variation of yields as costs of production were assumed to be proportional to yields (Antle and Capalbo 2001; Immerzeel et al. 2008). The weights with respect to climate change were assumed to be constant or the same because of the slow growth in area expansion (Ringler et al. 2010). In our analysis, three regions or locations were defined based on altitude including Upland, Middle and Lowland because altitudinal differences were considered to play a key role in influencing the local climate, farming practices and yields/returns in particular in Kabale district (Jan 2000; Papiernik et al. 2005; Sadler et al. 2005; Thornton et al. 2007; Thornton et al. 2009; Su et al. 2010)

Results and discussion

Descriptive results from stakeholder workshop

Results from a stakeholders' workshop showed unpredictable rainfall patterns, increased incidence of pests and diseases, declining soil fertility and shortage of land due to increase in population as the main factors affecting agricultural productivity. Farmers attributed the high incidence of pests and diseases to increasing temperatures and unreliable rainfall. Major crop diseases included bacterial wilt and late blight of potatoes, root rot of beans, caused by Fusarium and Pythium spp., Angular leaf spot, caused by Pseudocercospora, and bean rust that is caused by *Uromyceas phaseoli*. In sweet potatoes, farmers observed that the most common symptoms were sunken and mild vein yellowing of plants, leaf abscission, stunting, and wilting. These were considered to be symptoms of sweet potato virus diseases (SPVD) and bacterial infections for which the key control strategy is use of disease resistant varieties and disease free planting material (Ames et al. 1997). The impact of all these factors has been an increase in famine due to poor crop yields, reduced farm incomes, reduced livestock feed sources, lack of planting material and reduced access to water (Okonya and Kroschel 2013).

The coping mechanisms for unpredictable rainfall included swamp cultivation during the dry season, cultivation of drought resistant crops, mixed cropping, multiple cropping, cultivation of short duration crops (vegetables, water melon, and cereals), and increased usage of water harvesting methods based on traditional dams, flood irrigation, and micro-irrigation for vegetables. For diseases and pests, coping mechanisms included pesticide application, early planting, planting of pest and disease resistant varieties and increased practice of crop rotation. Coping mechanisms for land shortage include hiring land, intercropping, use of improved seeds and use of high yielding seeds. These results are consistent with the findings of Orindi and Eriksen (2005). Farmers also stated that the government provides improved planting material under the NAADS program to ensure that households are food secure. Nevertheless, most of the beneficiaries are the rich and politically connected. The poor, the old and vulnerable groups who cannot afford, let alone access, the new varieties, often miss out on government programs.

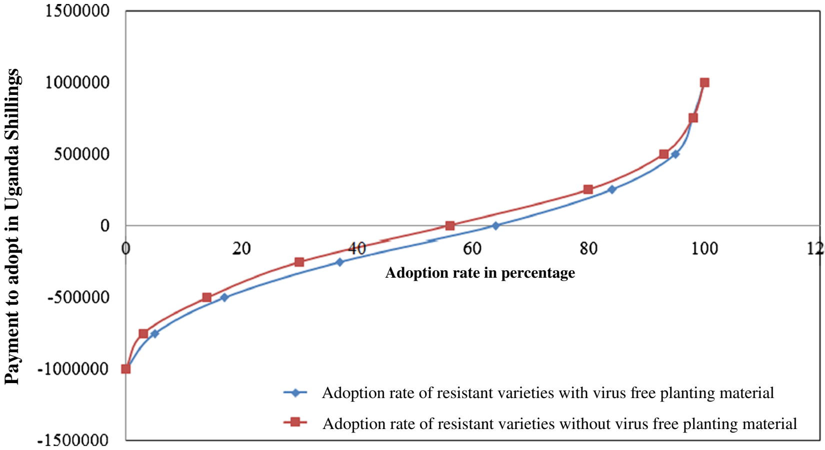
Results from trade-off analysis

As indicated above, system 1 was the current production system where farmers plant drought intolerant varieties and use virus infected planting material. Predicted yields using inherent productivity were used to estimate returns for system 2A and 2B. The simulations were then run comparing system 1 and 2A as well as system 1 and 2B. Based on these data and simulation, this study examined the three scenarios below:

(i) Adoption of pest and drought resistant sweet potato varieties with virus-free planting material versus virus-infected planting material with climate change impacts not incorporated.
(ii) Adoption of drought resistant varieties which are virus-free versus drought intolerant varieties and use of virus infected planting material varieties across different altitudes so as to test the hypothesis that adoption of improved sweet potato technologies varied within given agro-ecological zones under climate change.
(iii) Adoption of drought resistant varieties that are virus-free versus traditional varieties with and without subsidy under climate change. The objective was to assess the impact of supplying free planting material of the sweet potato technologies on adoption potential under climate change.

The results from trade-off analysis are presented in the Figs. 1, 2, and 3 below. The X axis represents the adoption level and Y axis shows the amount farmers need to be paid per hectare to achieve a given level of adoption in addition to the subsidy (free planting material). The positive section of the y axis represents the amount that farmers are willing to accept or receive to adopt a new technology to a given level while the negatives represent the amount in absolute terms that farmers are willing to pay to adopt the new technology to a given level.

Fig. 1 Trade-off curves showing how much sweet potato farmers are to be paid to attain a given level of adoption



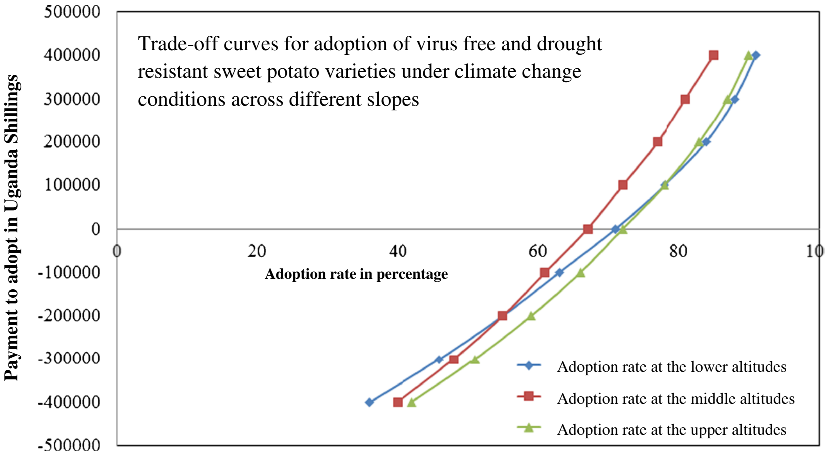
The trade-off analysis results for scenario 1 are presented in Fig. 1.

The results show the adoption rate of 65 % for planting pest and disease resistant varieties that are virus free without compensation and 57 % of the households would plant resistant varieties without compensation. Thus rendering drought tolerant varieties through thermotherapy in tissue culture plus virus indexing to test the cleaness of the vines of any virus remaining would lead to increase adoption potential by 8 %. Results also indicated that to raise adoption levels by about 20 % (from 65 to 85 % and 57 to 80 %), farmers need to be paid 250,000 Ugandan Shillings (US $125) per hectare to encourage them to adopt the new technologies. The economic rationale for investing 250,000 Uganda shillings per hectare to promote these sweet potato production technologies will depend on agro-ecological zones or landscape as shown in Fig. 2 and Table 2.

The results in Fig. 2 show that adoption levels of virus-free and drought resistant varieties at lower, middle and upper altitudes without payment are 71, 67 and 73 % respectively. The adoption level is lowest at medium altitudes and highest at upper altitudes. Payment of 250,000 Ugandan Shillings per hectare raises adoption in medium, upper and lower altitudes to about 78, 85 and 86 % respectively. As shown in Table 2, these values expressed as percentages of price per kilogram of sweet potato is 500 % for lower altitudes, 26 % for middle altitudes and 28 % for upper altitudes. The results suggest that investing 250,000 Ugandan Shillings per hectare to promote these sweet potato production technologies makes economic sense only if the payments to adopt are made to farmers at the upper and medium altitudes but not those at lower altitudes.

The low adoption potential in medium altitudes can be attributed to competition between settlements and crop production because of good drainage. Lower altitudes are often used for grazing animals and are frequently waterlogged thus not suited for settlement and sweet potato farming. The upper altitude areas are very steep and vulnerable to erosion and cannot be used for settlement. The existence of competing uses of land can explain why land size allocated to sweet potato is small at medium altitudes (Triomphe and Sain 2004). Therefore, the higher compensation pay required in medium altitude areas to increase adoption rate of sweet potato technology may be a result of high opportunity cost of land resulting from competing uses. As observed by Buckles (1999) in his study of adoption of the Mucuna system in Honduras, the opportunity cost of keeping land in the

Fig. 2 Adoption potential of using virus free planting materials, pest, and disease resistant varieties according to the nature of the slope



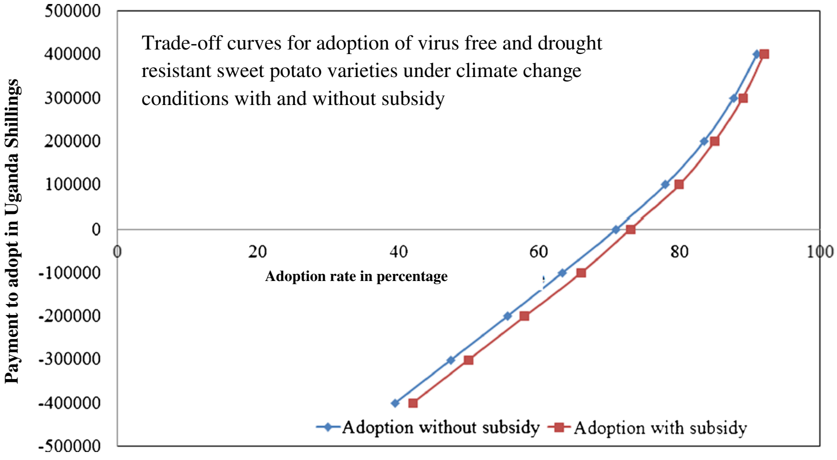


Fig. 3 Adoption potential of virus clean sweet potato with free planting (subsidized) material and with purchased planting material

Mucuna increased with increase in land converted to pastures for cattle production. These results clearly indicate that sustainable adoption of agricultural technologies in highland areas depends on the land value which varies with altitude.

Figure 3 presents the results of adoption rate of virus free and drought resistant sweet potato varieties when planting material is freely supplied to farmers and adoption rate when farmers buy the planting material under climate change conditions. The results indicate that 71 % would adopt virus free and drought resistant varieties even if the planting material was not subsidized compared to 73 % in the case of free planting material. The 2 % difference in adoption potential implies that a sweet potato vine subsidy would achieve little in terms of promoting adoption. This means that farmers would obtain planting material with or without compensation, probably because sweet potato is the main food security crop in Kabale and farmers would always adopt the technology if increase in yield (reduction in yield loss) were profitable (Zeller et al. 1998). The results further show that farmers do not adopt the technology as long as costs exceed benefits. Besides, the more risky the technology is, the higher the possibility that a farmer will not adopt or allocate resources to that technology (Neill and Lee 2001).

Conclusions and recommendations

Results from this study reveal that sweet potato producers from Kabale district in Uganda are experiencing the effect of climate change and that a sweet potato vine subsidy would achieve little in terms of promoting the adoption of new sweet potato technologies and would not benefit the rural poor. Moreover, paying farmers a subsidy to raise adoption of climate resilient sweet potato technologies would only be economically rational for farmers at medium and upper altitudes but not for lower altitudes. The analysis also established that in Kabale district, the opportunity cost of land is one of the critical determinants of sustainable adoption of improved agricultural technologies at least in as far as sweet potato technologies are concerned. Climate change policy needs to aim at enabling both the poor and the rich to benefit from the available adaptation strategies. This requires strengthening and building effective institutional frameworks and systems to promote climate change adaptation strategies of a public nature. The policy should also be able to target particular households on the basis of agro-ecological zone or vulnerability. Climate change policy should focus on reducing opportunity costs and transaction costs involved in adopting the adaptation strategies.

Table 2 Sweet potato yields, price, costs and returns from new technology under climate change

Region	Cost per ha (Ugx)	Yields per ha (kg)	Price per kg (Ugx)	Returns per ha (Ugx)	Subsidy per ha (Ugx)	Subsidy per kg (Ugx)	Subsidy:price ratio (%)
Lower slopes	168440.0	321.6	155.4	49956.1	250000.0	777.5	500.4
Middle slopes	40000.0	6223.6	155.4	966889.6	250000.0	40.2	25.9
Upper slopes	128920.0	5743.7	155.4	892324.3	250000.0	43.5	28.0

Source: Authors: The costs are computed by adding the cost from the household surveys and adoption costs. Yields and price values under climate change are derived by adjusting yield and prices obtained from field survey with climate change impacts shown in Table 1 and prices are means computed from household survey data. The returns per hectare are computed by multiplying adjusted yields and price. The subsidy per hectare is generated from model results and is divided by yields in kilograms in order to obtain the subsidy per kilogram. Per kg subsidy is divided by the adjusted price to generate the subsidy price ratio

Ugx Ugandan Shillings

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